

# The Cosmic Dust Analyzer for Cassini

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## ABSTRACT

The Cosmic Dust Analyzer (CDA) is designed to characterize the dust environment in interplanetary space, in the Jovian and in the Saturnian systems. The instrument consists of two major components, the Dust Analyzer (DA) and the High Rate Detector (HRD). The DA has a large aperture to provide a large cross section for detection in low flux environments. The DA has the capability of determining dust particle mass, velocity, flight direction, charge, and chemical composition. The chemical composition is determined by the Chemical Analyzer system based on a time-of-flight mass spectrometer. The DA is capable of making full measurements up to one impact/second. The HRD contains two smaller PVDF detectors and electronics designed to characterize dust particle masses at impact rates up to 104 impacts/second. These high impact rates are expected during Saturn ring plane crossings.

Keywords: cosmic dust, dust impact analyzer, Cassini Mission, Saturn

## 1. INTRODUCTION

### 1.1 Science Observations

The Cassini Cosmic Dust Analyzer (CDA) will provide direct observations of dust with masses between  $10^{-16}$  and  $10^{-6}$  g in interplanetary space and in the Jovian and Saturnian systems. The instrument will investigate dust physical, chemical and dynamical properties as functions of the distances to the Sun, Jupiter and Saturn, its satellites and rings, and it will study dust interactions with the Saturnian rings, satellites and magnetosphere. The chemical composition of interplanetary meteoroids will be determined and compared with asteroidal and cometary dust as well as Saturnian dust, ejecta from rings and satellites. The chemical composition of Jovian dust streams<sup>1</sup>, if they still exist at encounter, will be compared with the composition of Jovian satellites and rings determined by the remote sensing systems of the Galileo Mission. The chemical composition of dust in the Saturnian system will be compared to remote sensing determinations of Saturnian satellite compositions. The effect of electrical charging of dust in the magnetosphere will be studied including the effects on the ambient plasma, the dust trajectories and electrostatic particle disruption.

## 1.2 instrument Capabilities

The Cosmic Dust Analyzer<sup>1</sup> has been designed as a highly capable system for measurement of the mass, composition, electric charge, speed and flight direction of individual dust particles. The instrument has significant inheritance from previously developed dust instruments for interplanetary missions, but it has many innovative design components that optimize it for the Cassini Mission. CDA is a descendant of the dust detectors developed under the leadership of researchers at the Max-Planck-Institut für Kernphysik and flown on previous missions including the I 1110 S-2 satellite<sup>2</sup> and the Vega<sup>3</sup>, Giotto, Galileo<sup>4</sup> and Ulysses<sup>5</sup> missions. The Co-investigators on the CDA team are listed in Table 1.

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|------------------|---|
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| J. Svestka       | Prague Observatory (Czech Republic)                       |
| P. Lamy          | Laboratoire d'Astronomie Spatiale (France)                |
| G. Schwehm       | ESTEC (The Netherlands)                                   |
| O. Havnes        | University of Tromsø (Norway)                             |
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| T. Johnson       | Jet Propulsion Laboratory (U. S. A.)                      |
| A.J. Tuzzolino   | University of Chicago (U. S. A.)                          |
| H.A. Zook        | NASA Johnson Space Center (U. S. A.)                      |

Table 1. CDA Co-investigators

The Cassini Mission provides an excellent set of opportunities for extensive dust measurements in interplanetary space, the Jovian environment and the Saturnian environment. Because of this range of mission observation opportunities, the CDA instrument has been designed to accommodate a wide range of observing conditions, and, in most ways, its performance has also been enhanced over the predecessor instruments. The low dust flux conditions of interplanetary space require a large aperture instrument to get adequate impact statistics. However the extremely high dust fluxes expected during the Saturn ring plane crossings require a detector system that will not saturate or be damaged during repeated ring encounters. At the same time, the success of the Giotto and VEGA dust mass spectrometers encouraged the incorporation of a similar chemical analysis capability in the CDA instrument. The initial and continuing results from the Ulysses and Galileo instruments has shown the value of making dust observations in 4 $\pi$  space<sup>6,7</sup>. But whereas those missions are being conducted with spinning spacecraft (or partially spinning in

the case of Galileo), the Cassini spacecraft is only periodically, and slowly rotating, so that CDA has been designed with a self articulation capability in order to cover  $2\pi$  space with an inertial spacecraft.

Perhaps the most exciting capability of CDA will be the ability to directly measure the chemical composition of the dust particles impacting the system. The only other direct measurements of solar system dust composition were made near Halley by the dust instruments on the Giotto and VEGA spacecraft. The mass spectrometers on these missions had very high mass resolving power, but had only very small impact ionization targets. To enable statistically realistic measurement opportunities even in interplanetary space, CDA is designed with an about ten-times larger target. Thus, with CDA, for the first time, it is expected to be possible to make assignment of dust sources on the basis of the dust composition in interplanetary space as well as in the Jovian and Saturnian systems. The dust experiments on Galileo and Ulysses, which do not have chemical analysis capability, can classify dust sources on the basis of dust arrival directions, particle masses, particle velocities, and the proximity to specific potential sources. Thus, for instance, on the basis of these parameters they can tentatively distinguish interstellar dust from dust that more likely originates from comets, asteroids or planets and moons. However, direct compositional measurements will add a firmer basis for making these distinctions and for identification of additional dust sources. In the Saturnian system it may be possible to relate individual particles to specific icy satellite sources, even far from the satellites.

### 1.3 history of dust measurements

Cassini was the first to recognize dust in interplanetary space through his telescopic observations of the Zodiacal Light in the 17th Century and his attribution of it to the presence of dust around the sun. The first direct (contact) measurements of solar orbiting dust were made by the Pioneer 8 and 9 spacecraft. The Pioneer 8 and 9 spacecraft could measure particle masses above about 10-16 kg and had sensitive areas only 10% that of CDA.

The first direct measurements of the dust in the Saturnian system were made by the Pioneer 10 and 11 spacecraft in the early 70s. These detectors had 7 orders of magnitude lower mass sensitivity than CDA will have. The only other direct detection of Saturnian ring dust was made by the plasma wave experiment on Voyager 2 spacecraft. A tabulation of the characteristics of the previous dust detectors has been published<sup>5</sup>.

The design measurement capabilities of CDA are listed in Table 2.

## 2. INSTRUMENT DESIGN

The instrument contains a number of different subsystems that are designed to optimize information obtained about dust impacts under different conditions. The major detection systems are called the Dust Analyzer (DA) and the High Rate Detector (HRD). The DA will make extensive, detailed measurements on the dust when the impact rates are below about one per second. On the other hand, the HRD is intended to make a simpler set of measurements when fluxes are very high, such as during ring plane crossings. Figure 1 is a photograph of the engineering model configuration. The instrument barrel is about 450 mm in diameter.

## 2.1 Dust Analyzer

The DA makes measurements of the inherent dust charge, velocity, mass and chemical composition for impact rates up to one per second. The measurements electronics are capable of higher rates, however limitations on power dissipation as well as practical data volume limitations require limiting impact triggering rates.

| Parameter                              | Range  |
|--|--|
| Dust velocity                          | 1 - 100 km/s   |
| Dust Mass range for chemical analysis  | $10^{-16} - 10^{-9}$ g at 20 km/s                                      |
| Counting rate range                    | 0.1 - 100 impact/s   |
| Basic field of view                    | 90 degree full cone for DA, $2\pi$ sr for the HRD                      |
| Angular resolution                     | 10 degrees in one plane, depending on charge, direction and statistics |
| Dust Charge                            | $10^{-15} - 6 \times 10^{-13}$ C at 2 - 40 km/s                        |
| Chemical analyzer mass resolving power | 20-40 m/dm   |

**Table 2.** (DA) design measurement capabilities.

Figures 2a and 2b are functional schematic diagrams of the system with some representative signals shown for two different types of dust impact events. Figure 2a shows the trajectory of a particle that strikes the Chemical Analyzer target with typical signals seen at the sensing systems. Figure 2b shows the trajectory and signals for a particle that strikes the Dust impact Ionizer. In the first case, chemical analysis is performed but in the second case no chemical information is obtained.

Charged dust particles are first detected during their passage through the charge sensing grid structure. There are four grids in the structure, top and bottom grounded grids, and two sensing grids tilted at 9 degrees to the axis of the DA barrel. The rise time, duration, magnitude and fall time of the signals in the center grid pair permit calculation of the particle charge, velocity, and angle of the velocity vector with respect to one plane. These signals are all digitized and stored for downlink later.

When the dust particle strikes the Chemical Analyzer (CA) Target with sufficient velocity, as in Figure 2a, the impact creates a plasma containing ions and electrons from the particle and the target. The strong electric field between target and the Chemical Analyzer Grid quickly separates the positive and negative charges and accelerates the ions toward the Ion Collector and electron multiplier. The 1000 V bias of the CA Target and 350 V bias on the Ion Collector is sufficient to allow time-of-flight mass spectrometry with a resolving power of up to  $M/\Delta M=50$ , depending on the initial ion energies. The total ion charge at the electron multiplier for any particular ion mass-to-charge ratio is primarily a function of the particle mass and the particle and target elemental compositions, but it is also a function of the impact velocity. The high speed digitization of the output signals at the electron multiplier is typically triggered by the charge collected on the CA target or grid, but can be triggered by other signals. The ion transit time between the triggering and the arrival at the multiplier is determined by the ion mass to charge. The transit times and ion intensities are measured by digitizing the multiplier signal for 5  $\mu$ s at a rate of 100 MHz and the data stored for downlink. Additional details of CDA and the design of the DA have been published<sup>8</sup>.

The signals at the output of the chemical analysis time-of-flight electron multiplier must cover a very large dynamic range for two reasons. A wide dynamic range allows measurement of a large range of ion abundances for any one impact, but, more importantly, a wide dynamic range is needed to make chemical analysis measurements over six orders of magnitude in range of particle masses impacting the system. Because of the random nature of the impact events and the short ion time of flight, it is clearly impossible to make real-time gain changes for each event. An innovative solution to this problem has been created through the development of the Dynode Logarithmic Amplifier. This system sums the linear signals from six different dynodes of the Johnston MM-1 multiplier in such a way that for large impacts the amplifiers for highest gain dynodes produce fixed outputs that sum with the Unsaturated low gain dynode signals.

As shown in Figure 2b, if the dust particle strikes the impact Ionization Detector (1 ID), an annulus on a sphere, an impact plasma is created and the ions and electrons are separated by the electric field between the biased central grid system around the multiplier and the grounded target. The digitized rise times, collected charge on the IID, IonGrid and electron multiplier permit calculation of the particle mass based on laboratory determination of the  $c$ ,  $\alpha$ , and  $\beta$  coefficients of the empirical equation  $Q = c m^{\alpha} v^{\beta}$ . The velocity of impact is determined from the laboratory-established relationship between rise time of the target and ion-grid signals and the particle velocities.

The signals measured in the normal operation of the Dust Analyzer are summarized in Table 3.

| Measurement channel               | Measured quantity             | Measurement range and risetime                           | Particle parameter   | Digitization frequency in MHz |
|-----------------------------------|-------------------------------|--|--|-------------------------------|
| QP - Entrance grids               | Induced charge                | $10^{-15}$ - $6 \times 10^{-13}$ C,<br>0.25 - 80 $\mu$ s | Speed: 2-40 km/s.<br>Trajectory in one plane.<br>Charge.             | 6                             |
| QI - Impact Ionization Detector   | Electrons generated on impact | $10^{-14}$ - $1 \times 10^{-11}$ C,<br>0.5 - 150 $\mu$ s | Mass: $1 \times 10^{-15}$ - $1 \times 10^{-9}$ g<br>Speed: 2-40 km/s | 3                             |
| QC - Chemical Analyzer Target     | Electrons generated on impact | $10^{-14}$ - $10^{-18}$ C,<br>0.2 - 10 $\mu$ s           | Mass: $1 \times 10^{-15}$ - $1 \times 10^{-9}$ g<br>Speed: 2-40 km/s | 6                             |
| QA - Chemical Analyzer Grid       | Ions generated on impact      |  |  | trigger only, not digitized   |
| QI - Ion Grid                     | Ions generated on impact      | $10^{-14}$ - $10^{-8}$ C,<br>0.2 - 90 $\mu$ s            | Mass and impact speed  | 6                             |
| QM - Multiplier.<br>Dynode signal | Ions generated on impact      | $4 \times 10^{-14}$ - $4 \times 10^{-8}$ C,<br>10 ns     | Chemical composition   | 100                           |
| QM2 - Multiplier<br>Anode signal  | Ions generated on impact      |  |  | trigger only, not digitized   |

**Table 3.** Signals measured by the Dust Analyzer in normal operations.

## 2.2 High Rate Detector

The HRD consists of two sensors and circuitry to record impact data. The two sensors are based on the principles developed previously by Simpson and Tuzzolino<sup>9</sup>. One sensor is 50 cm<sup>2</sup> disk of 28  $\mu$ m thick polyvinylidene fluoride (PVDF) film. The other sensor is a 10 cm<sup>2</sup> disk of 611111 thick PVDF. The two sensors are used for redundancy, to provide two different, partially overlapping mass detection ranges, and

to provide an increased dynamic range of counting rates. The HRD sensor system is identified in Figure 1. Each sensor has a nominal  $2\pi$  hemispherical field of view centered on the DA field of view. The PVDF is permanently polarized and has metallized surfaces to permit sensing of the polarization charge. If a dust particle impacts a film with sufficient velocity (more than a few km/s depending on size), it will punch a hole in the film (Figure 3.). This will result in a change in the charge of the film (depolarization) that is sensed by the electronics. The magnitude of the depolarization charge is measured at four fixed thresholds for each sensor. At low impact rates, the thresholds triggered and the impact times are recorded and the counters corresponding to the thresholds are incremented for later transmission to the CDA computer. If very high impact rates are expected, the HRD operation can be changed by command so that the individual impact events are not recorded, and only the eight threshold counters are used. The rate of reading and resetting the counters is also commandable.

The relationship between the magnitude of the charge and the mass and velocity of the impacting particles is calibrated on the ground. It is not possible from the HRD measurements alone, to determine independently the mass and velocity of the particles. However, since the HRD will typically be making measurements during passage through Saturn's rings, the impact velocities for the ring particles will be calculable from orbital parameters, so the mass of the particles can also be calculated from the prelaunch calibrations. Particle composition has only a minor effect on the mass determination,

### 3. INSTRUMENT OPERATIONS

The CDA instrument needs to be in operation a major fraction of the time after launch in order to characterize the dust environment in the solar system out to Saturn. The experience with the Ulysses and Galileo missions clearly show that it is not sufficient to occasionally sample certain directions. The early identification of the Jovian dust streams by the Ulysses experiment was possible due to the high duty cycle sampling over large solid angles<sup>1</sup>. Whereas the Ulysses and Galileo dust instruments have fixed FOV relative to the spacecraft, CDA has the capability of reorienting its FOV with respect to the spacecraft to insure the most effective sampling of the dust environment.

During most of the Cassini mission the CDA instrument will be in a low dust flux environment so the Dust Analyzer will be the primary data source. In this case the desirable spacecraft state is in the "rotisserie"; fields and particles rotation. This rotation allows the instrument to survey the  $4\pi$  space on a relatively short time scale. To cover the  $4\pi$  space, the instrument will be rotated occasionally between selected positions around the articulation axis. The frequency of articulation may be only every few weeks in interplanetary cruise, once per day in orbital mist or nearly continuously near the ring plane crossings. The articulation axis of the instrument is nearly normal to the spacecraft Z-axis and provides the field of view of the IDA Dust Analyzer portion of the experiment illustrated in Figure 4. The four near-circles are the instantaneous FOVs of the four reference positions of CDA. The rectangular area represents the full  $4\pi$  desired coverage.

The spacecraft rotation and instrument articulation are important not only for large observing solid angle but also to enable determination of the dust velocity vectors. Although the IDA grid system can measure one component of the velocity vector of charged dust, the portion of dust that is charged is not known, and theoretical considerations show that it might be very low. Thus the best way to determine dust arrival directions is through scanning the instrument field of view through all possible directions in a cyclic fashion

and determining arrival directions from the statistics of when impacts occur. By choosing appropriate rate for articulation and rotation, spatial and temporal variations in dust arrival can be separated.

During ring plane crossings the operation of the spacecraft and CDA instrument will probably be quite different. Because the orientation of the spacecraft will be quite restricted for safety reasons, CDA articulation may be needed every few minutes to adequately separate spatial and temporal ring dust variations during the hour or so around the ring plane crossing. During the ring plane crossings, the HRD will be the primary measurement system because the DA cannot make impact measurements at faster than one per second. The HRD can register impacts up to  $10^4$  per second with insignificant deadtime.

The CDA data return is very flexible. Only 0.5 kbits/s is needed from the instrument to the SC to support the highest data acquisition rates. Full data from the DA and HRD can be returned at this rate. This low data rate will be easily supported by the available downlink rates for most of the mission. However on the other hand, early in the mission when average downlink rates are very low, the CDA data can be reformatted with onboard data processing so that the most valuable information can be returned at less than 1 bit/s. Because the CDA measurements are triggered by impacts, it does not normally generate any science data if there is no dust. However on board noise sources such as Sounder operations, and planetary plasmas can produce random triggers if care is not used to prevent it. Both the DA and HRD have commandable triggering threshold adjustments that will insure that noise triggers are minimized and that the best data are returned under all conditions.

#### 4. ACKNOWLEDGMENTS

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#### 5. REFERENCES

1. E. Grün, H. A. Zook, M. Baguhl, A. Balogh, S. J. Bame, H. Fechtig, R. Forsyth, M. S. Hanner, M. Horanyi, J. Kissel, B.-A. Lindblad, D. Linkert, G. Linkert, I. Mann, J. A. M. McDonnell, G. E. Morfill, J. L. Phillips, C. Polansky, G. Schwehm, N. Siddique, P. Staubach, J. Svestka, and A. Taylor, "Discovery of Jovian dust streams and interstellar grains by the Ulysses spacecraft," *Nature*, Vol 362, pp. 428-430, April 1993.
2. H. Dietzel, G. Eichhorn, H. Fechtig, E. Grün, H. J. Hoffmann and J. Kissel, "The HEOS 2 and Helios micrometeoroid experiments," *J. Phys. (E) Sci. Instr.*, Vol 6, 209.
3. J. Kissel, R. Z. Sagdeev, J. L. Bertaux, V. N. Angarov, J. Audouze, J. E. Blamont, K. Buchler, E. N. Evlanov, H. Fechtig, M. N. Fomenkova, H. von Hoerner, N. A. Inogromov, V. N. Kromov, W. Knave, F. R. Krueger, Y. Langevin, V. B. Leonas, A. C. Levassere-Regourd, G. G. Managadze, S. N. Podkolzin, V. D. Sapiro, S. R. Tabaldyev and B. V. Zubkov, "Composition of Comet Halley Dust Particles from Vega Observations," *Nature*, Vol. 321, pp 280-282, 1986.
4. E. Grün, H. Fechtig, M. S. Hanner, J. Kissel, B.-A. Lindblad, D. Linkert, D. Maas, G. E. Morfill, and H. A. Zook, "The Galileo Dust Detector," *Space Sci. Rev.* Vol 60, pp 317-340, 1992.

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#### 5. REFERENCES

1. E. Grün, J. A. Zook, M. Baguhl, A. Balogh, S. J. Bame, H. Fechtig, R. Forsyth, M. S. Hanner, M. Horanyi, J. Kissel, B.-A. Lindblad, D. Linkert, G. Linkert, I. Mann, J. A. M. McDonnell, G. E. Morfill, J. L. Phillips, C. Polansky, G. Schwehm, N. Siddique, P. Staubach, J. Svestka, and A. Taylor, "Discovery of Jovian dust streams and interstellar grains by the Ulysses spacecraft," *Nature*, Vol 362, pp. 428-430, April 1993.
2. H. Dietzel, G. Eichhorn, H. Fechtig, E. Grün, H. J. Ioffman and J. Kissel, "The HEOS 2 and Helios micrometeoroid experiments," *J. Phys. (E) Sci. Instr.*, Vol 6, 209-217, 1973.
3. J. Kissel, R. Z. Sagdeev, J. L. Bertaux, V. N. Angarov, J. Audouze, J. E. Blamont, K. Buchler, E. N. Evlanov, H. Fechtig, M. N. Fomenkova, J. L. von Hoerner, N. A. Inogamov, V. N. Khromov, W. Knabe, E. R. Krueger, Y. Langevin, V. B. Leonas, A. C. Levasseur-Regourd, G. G. Managadze, S. N. Podkolzin, V. D. Shapiro, S. R. Tabaldyev and B. V. Zubkov, "Composition of Comet Halley Dust Particles from Vega Observations," *Nature*, Vol. 321, pp 280-282, 1986.
4. E. Grün, H. Fechtig, M. S. Hanner, J. Kissel, B.-A. Lindblad, D. Linkert, D. Mm, G. E. Morfill, and J. A. Zook, "The Galileo Dust Detector," *Space Sci. Rev.* Vol 60, pp 317-340, 1992.

5. E. Grün, H. Fechtig, R. H. Giese, J. Kissel, D. Linkert, D. Maas, J. A. M. McDonnell, G. E. Morfill, G. Schwehm and H. A. Zook, "The Ulysses Dust Experiment," *Astron. Astrophys. Suppl.*, Ser. 92, pp41 1-423, Jan. 1992.

6. E. Grün, M. Baguhl, N. Divine, H. Fechtig, D. P. Hamilton, M. S. Hanner, J. Kissel, B.-A. Lindblad, D. Linkert, G. Linkert, I. Mann, J. A. M. McDonnell, G. E. Morfill, C. Polanskey, R. Riemann, G. Schwehm, N. Siddique, P. Staubach and H. A. Zook, "Three years of Galileo dust data," *Plan. & Space Sci.*, Vol 43(8), pp953-969, Aug. 1995.

7. E. Grün, M. Baguhl, N. Divine, H. Fechtig, D. P. Hamilton, M. S. Hanner, J. Kissel, B.-A. Lindblad, D. Linkert, G. Linkert, L. Mann, J. A. M. McDonnell, G. E. Morfill, C. Polanskey, R. Riemann, G. Schwehm, N. Siddique, P. Staubach and H. A. Zook, "Two years of Ulysses dust data," *Plan. & Space Sci.*, Vol 43(8), pp971-999, Aug. 1995.

8. P. R. Ratcliff, J. A. M. McDonnell, J. G. Firth and E. Grün, "The Cosmic Dust Analyser," *J. Brit. Interplan. Soc.*, Vol 45, pp375-380, 1992.

9. J. A. Simpson and A. J. Tuzzolino, "Polarization polymer films as electronic pulse detectors of cosmic dust particles," *Nucl. Instr. and Meth.*, Vol. A236, 187, 1985

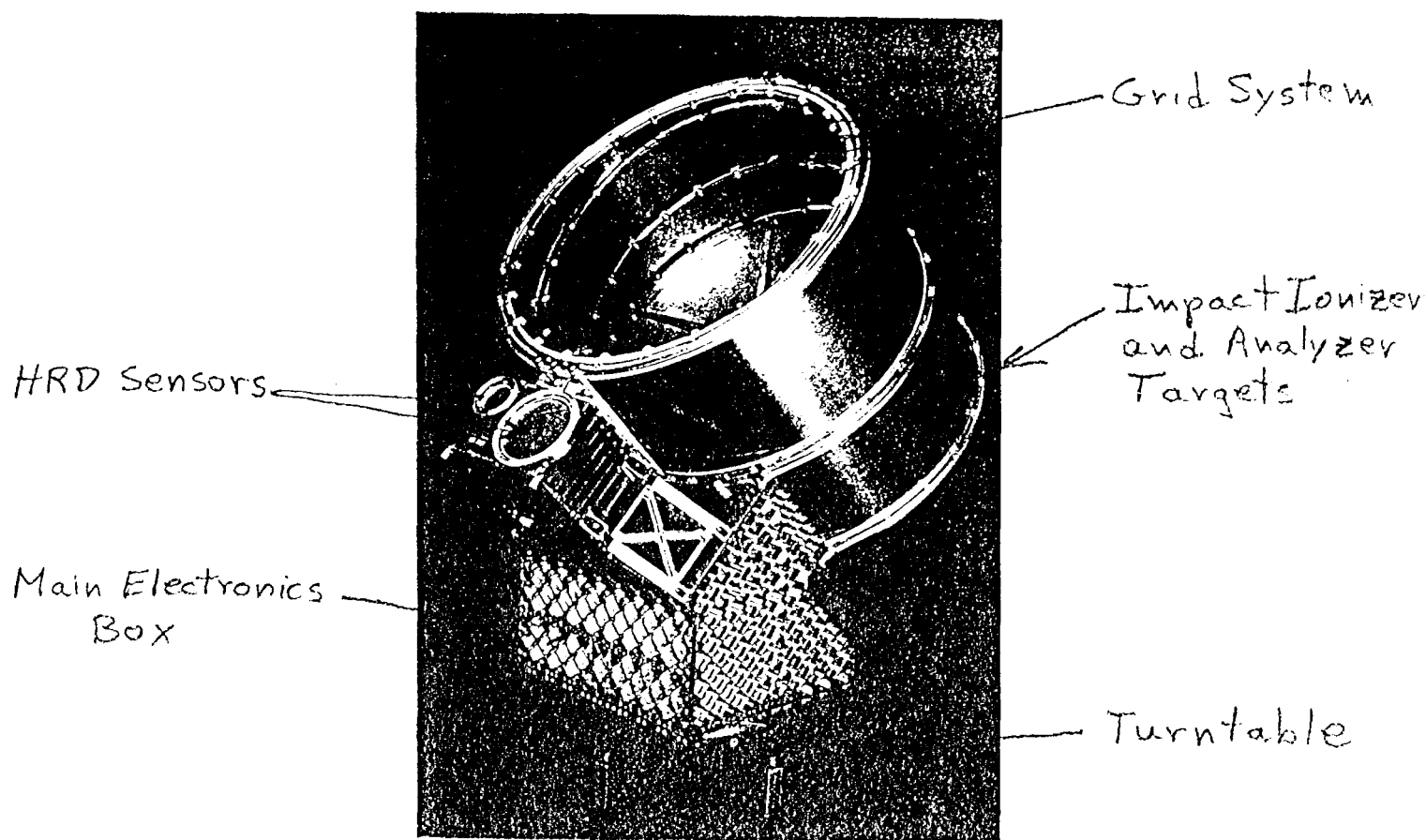


Figure 1. Photograph of CDA engineering model without thermal blankets.

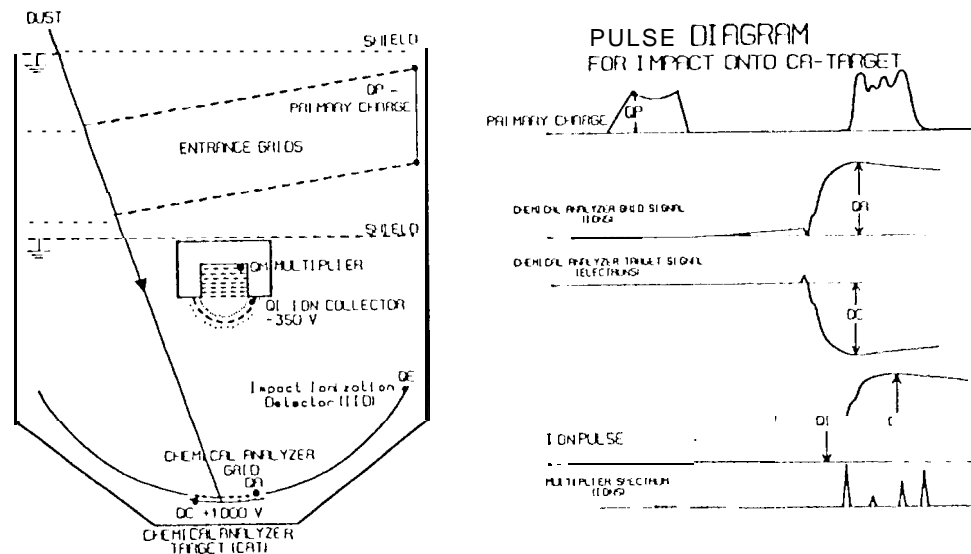


Figure 2a. Schematic of the CDA Dust Analyzer system with representative signals for a dust particle impacting the Chemical Analyzer Target.

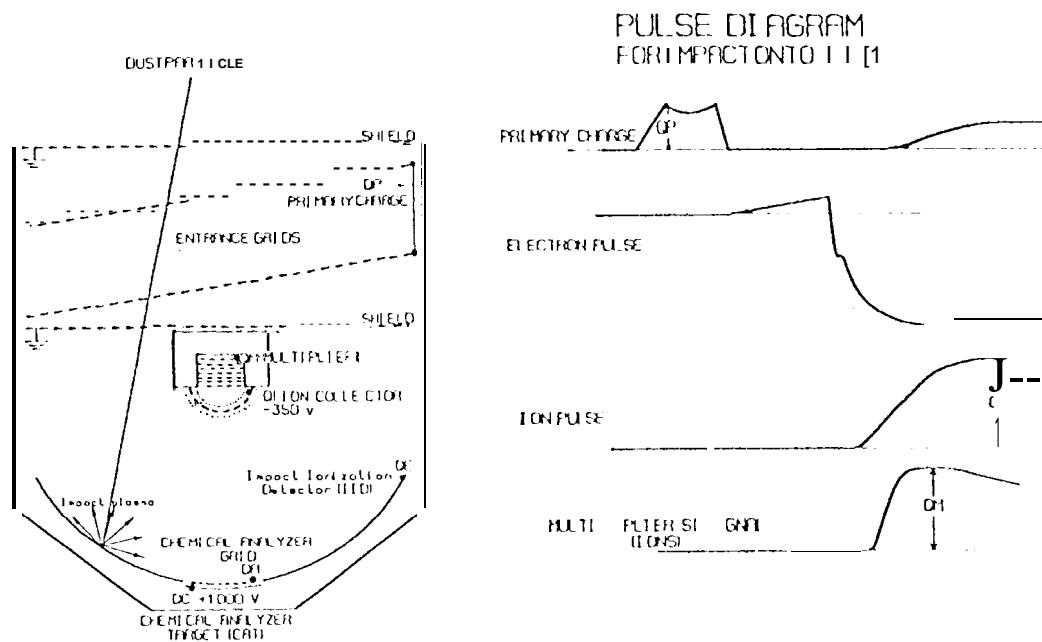


Figure 2b. Schematic of the CDA Dust Analyzer system with representative signals for a dust particle impacting the Impact Ionization Detector.

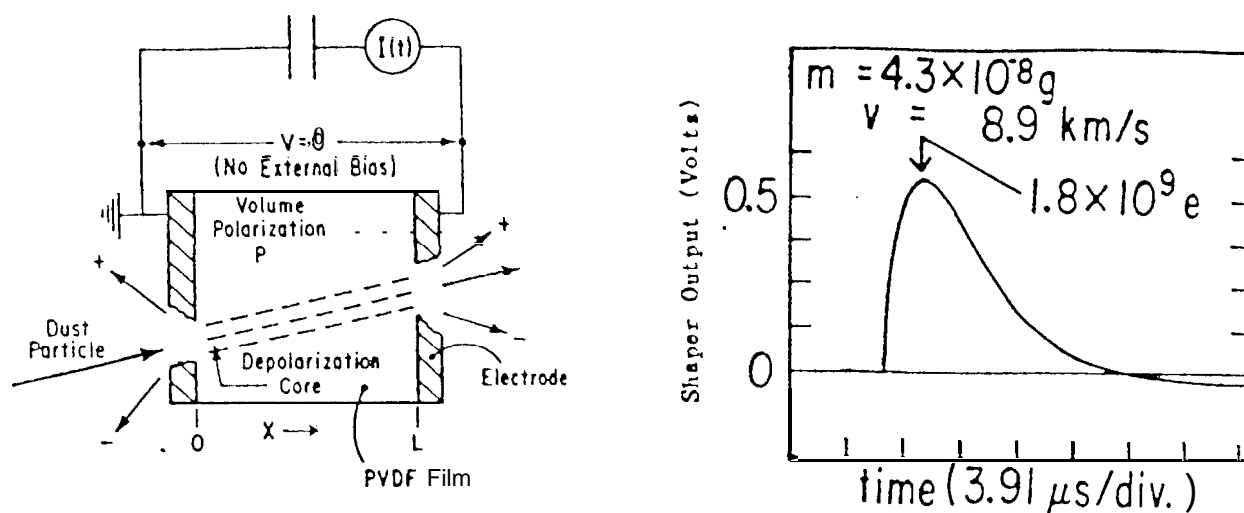


Figure 3. Schematic drawing of the HRD polarized PVDF sensor. An incident high-velocity dust particle penetrates the sample, resulting in complete depolarization within and near the crater formed. The fast current pulse is amplified by a shaping amplifier as shown at the right.

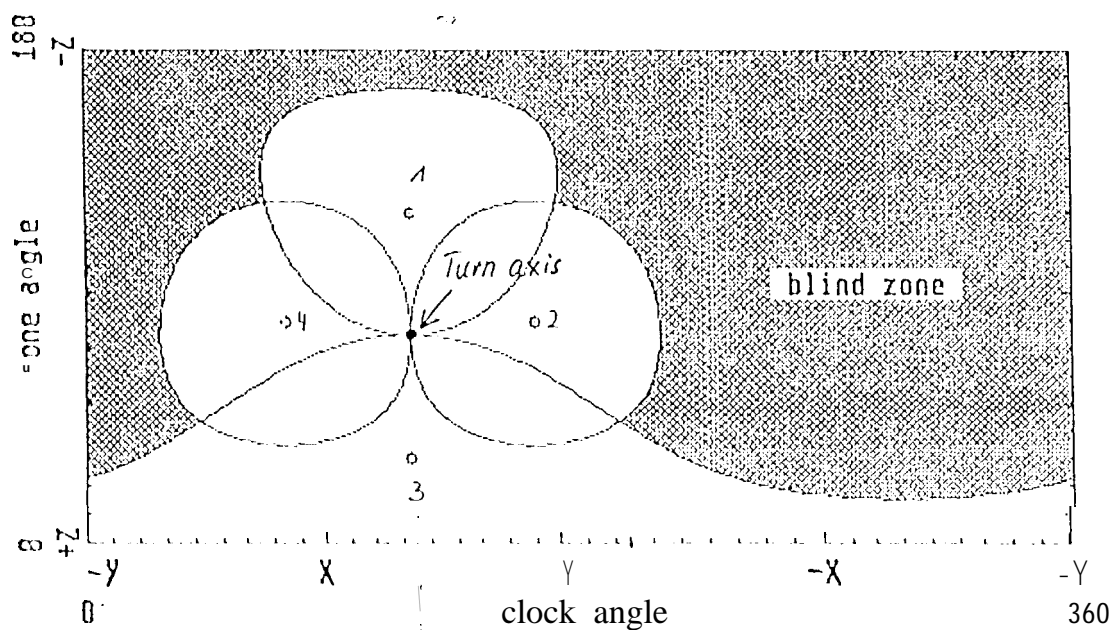


Figure 4. Dust Analyzer fields of view in the four CDA reference positions.